PB86-110731

Disinfection, 1985

(U.S.) Environmental Protection Agency
Cincinnati, OH

1985

U.S. Department of Commerce
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1. REPORT NO. EPA/600/J-85/171	2.	3. PB86-110731
4. TITLE AND SUBTITLE Disinfection (1985) (Journal Version)		5. REPORT DATE 1985 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Albert D. Venosa and Russell Isaac		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Water Engineering Research Laboratory, Cin., OH U.S. Environmental Protection Agency 26 West St. Clair Street Cincinnati, OH 45268		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES REF: JWPCF, 57(6):548-555, June 1985

16. ABSTRACT

This article is a summary of the literature published in the year 1984 on the topic of wastewater and water disinfection. It consists of a section on the microbiology and kinetics of disinfection and several sections related to the chemistry of disinfection, including analytical methods, reactions, and products.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* Unclassified 20. SECURITY CLASS *(This page)* Unclassified	21. NO. OF PAGES 9 22. PRICE $9.95

EPA Form 2220-1 (9-73)

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NATIONAL TECHNICAL
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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA/600/J-85/171
JOURNAL ARTICLE

Disinfection

Albert D. Venosa, Russell Isaac

MICROBIOLOGY

A proceedings of a workshop on wastewater disinfection alternatives was published in late 1983.[1] Topics discussed included the history of wastewater disinfection; regulatory trends; and design, operation, and effectiveness of ultraviolet light, chlorine, chlorine dioxide, and ozone. The final chapter dealt with microbial risk assessment associated with various disinfection policies. A wastewater disinfection state-of-the-art report[2] appeared in 1984 summarizing the latest knowledge of environmental and health aspects of disinfection and the mechanism of action and use of the disinfectants chlorine, ozone, bromine chloride, chlorine dioxide, and ultraviolet light.

Seyfried *et al.*[3] conducted an intensive investigation of the impact of chlorinated and unchlorinated wastewater treatment plant effluents on microbial pollution of surface waters. They found that staphylococci, *Pseudomonas aeruginosa*, total coliforms, fecal coliforms, and fecal streptococci had a 0.02 to 0.008% survival rate after chlorination. Viruses were detected in 100% of raw wastewater samples, 63% of non-chlorinated effluent, 40% of chlorinated effluent, and 4% of receiving water samples. Simmonds *et al.*[4] observed that, although virus numbers were reduced by chlorine treatment, they were still detectable, not only in 11 of the 16 chlorinated samples tested, but also at considerable distances from the point of discharge. They concluded that the possibility of sporadic undetected infection exists. Goyal *et al.*[5] measured the occurrence of enteric viruses beneath three different sites where slow rate wastewater irrigation of cropland was practised. Enteric viruses were isolated from wells beneath all sites, but the lowest frequency of isolation was from wells beneath the one site practising chlorination before application by spray irrigation. Hopkins *et al.*[6] reported a rotavirus-caused gastroenteritis outbreak in Eagle-Vail and Avon, Colo., and attributed the outbreak in part to a breakdown in the Eagle-Vail treatment plant chlorinator, which was the only effective barrier between the toilets of Vail and the water taps of Eagle-Vail and Avon. Berk and Botts[7] studied the growth of ciliated protozoa on live and dead bacteria, the latter having been previously treated with chlorine or gamma-radiation. The ciliates used dead bacterial cells as a food source but exhibited lower productivity compared with living bacteria. Additionally, the mode of inactivation did not appear to matter in the suppression of ciliate growth. Thus, because ciliates did not avoid ingesting chlorine-inactivated bacteria in the presence of living bacteria, populations of protozoa may be affected by non-discriminatory feeding in areas of streams where chlorine from effluents is not toxic to the protozoa, provided that the load of dead cells discharged is not large enough to offset the decreased yield resulting from feeding on dead cells. Sanders[8] tested the ability of marine phytoplankton to grow in chlorinated estuarine water that had been stored for 10 to 35 days. Although total residual chlorine compounds were undetectable, two species did not grow even after the water had been aged 35 days. A more resistant species grew in chlorinated water aged 23 or 35 days but not in water aged 10 days.

Levy *et al.*[9] developed an experimental procedure to study the association of selected bacteria and macroinvertebrates and their response to free available chlorine (FAC) disinfection. Unassociated *Escherichia coli* and *E. cloacae* populations were observed to decrease to less than 1% of their zero time controls within 1 minute of contact time, whereas more than 2% of the associated *E. coli* and 15% of the associated *E. cloacae* populations remained viable after 60 minutes of contact at 1.0 mg/L FAC. The method can be used to ascertain whether a macroinvertebrate serves to breach the chlorine disinfection barrier, protects potential bacterial pathogens from disinfection, and possibly allows for subsequent pathogen multiplication within a water distribution system. Murray *et al.*[10] found that chlorination of raw wastewater and secondary effluent, while initially lowering the total number of bacteria, substantially increased the proportions of antibiotic-resistant, potentially pathogenic organisms. The increase was most marked after regrowth was allowed to occur following chlorination.

Gasser[11] found that successful disinfection (defined as achievement of a total coliform limit of 2.2/100 mL) of unfiltered nitrified pond effluent depended on initial concentrations of ammonia-N and nitrite-N. At ammonia-N $\leq$ 0.1 mg/L and nitrite-N $\geq$ 1.0 mg/L, chlorine was generally ineffective even at doses up to 50 mg/L and 180 minutes contact time. If the nitrite-N was $\leq$1.0 mg/L, chlorine was more effective but the limit was inconsistently achieved. At ammonia-N $\geq$ 0.3 mg/L, chlorine doses of 10 mg/L nearly always disinfected the pond effluent in 60 minutes contact, despite nitrite-N as high as 4.8 mg/L. Polprasert and Rajput[12] investigated the die-off patterns of fecal coliforms in waste stabilization pond effluents containing 100 to 400 mg/L algae. The extent of inactivation was proportional to the initial chlorine dose and contact time and inversely proportional to the algal concentration.

Dubov *et al.*[13] successfully disinfected municipal wastewater effluent with sodium hypochlorite prepared by bipolar electrolysis of salt solutions using titanium oxide-ruthenium oxide anodes. A higher concentration of salt was required for electrolysis at winter temperatures than at summer temperatures.

Harakeh[14] found that the disinfection action of chlorine against poliovirus 1 was enhanced additively by either chlorine dioxide, ozone, or acid. Churn *et al.*[15] studied the free chlorine inactivation kinetics of H-1 parvovirus as a model for the

Journal WPCF, Volume 57, Number 6
pp 548-555, June 1985

Norwalk agent, a causative agent of waterborne gastroenteritis. The time required for 99% inactivation of H-1 parvovirus at pH 7.0, 20°C, and a free chlorine dose of 0.2 mg/L was 3.2 minutes. The same investigators[16] attempted to define the mechanism of inactivation and found that the initial action of chlorine on the H-1 parvovirus was on the viral capsid. The particular spatial arrangement of the capsid proteins was altered, thereby adversely affecting adsorption by host cells. Berman and Hoff[17] evaluated the inactivation kinetics of free and cell-associated simian rotavirus SA11 by chlorine, chlorine dioxide, and monochloramine at 5°C and pH 6 to 10. Chlorine and chlorine dioxide, each at a concentration of 0.5 mg/L and at pH 6 and 10, respectively, inactivated 99% of both virus preparations within 4 minutes, whereas 10 mg/L of monochloramine at pH 8 required more than 6 hours for the same amount of inactivation. Ward *et al.*[18] demonstrated with pure cultures that inorganic chloramines can be nearly equally effective as free chlorine in inactivating microorganisms in water if the proper conditions exist. The most important conditions were pH < 7.5, separate addition of free chlorine and ammonia (as opposed to pre-formed chloramines), and relative concentrations of chlorine and ammonia. Engel *et al.*[19] measured the resistance of *Naegleria gruberi* cysts to chlorine in the presence of cyanuric acid at pH 5 and 7. The predominant cysticide was hypochlorous acid; no measurable cysticidal effect was observed for the chlorinated cyanurate species. A resin-I_3 column developed by Marchin *et al.*[20] effectively precluded excystation of *Giardia muris* and *G. lamblia* at 4 and 25°C. Partial reversal of the inhibition occurred when sodium thiosulfate was applied to column eluates containing the cysts.

Mayack *et al.*[21] compared chlorine and chlorine dioxide for controlling biofouling in stainless steel heat exchangers. Continuous application of 0.15 mg/L chlorine was more effective than four 15-minute, 1.0 mg/L chlorine applications per day or one 60-minute, 1.0 mg/L chlorine application. In contrast, low level continuous chlorine dioxide treatment was similar to intermittent addition. Overall, chlorine dioxide was more effective than chlorine in controlling biofouling. Schmidt[22] found that combined application of chlorine and non-ionic dispersal agents was effective in controlling build-up of microorganisms in industrial cooling water and was favorable both economically and ecologically. Continuous application of 5 to 30 mg/L dispersant with intermittent application of chlorine providing a 0.5 to 1.0 mg/L free residual was the proper combination. Wilde *et al.*[23] subjected three types of fish to intermittent exposures to total residual chlorine (TRC) and chlorine dioxide, thereby simulating biofouling control conditions at nuclear reactor heat exchangers. LC_{50} values indicated that ClO_2 was 2 to 4 times more toxic than TRC to juvenile and 1-year old fathead minnows and young-of-the-year bluegills.

Junkins[24] compiled and reported design and operational information on the use of ozone and ultraviolet light (UV) at selected existing facilities. Most of the operational and maintenance problems experienced with ozone disinfection systems were site-specific and not prevalent problems that repeatedly occurred at all sites. Very limited information was available on UV systems. Bancroft *et al.*[25] found good correlations between microbial inactivation and the organic content of water. Initial death rates were related to the quantity of ozone applied, which was in turn related to the total organic carbon (TOC) and the oxidation competition value. The latter term is a measure of the competition for ozone by a reference solute and the TOC. Application of ozone to river water enhanced the regrowth of *Pseudomonas aeruginosa*. Treatment of a wide variety of lignocellulosic biomass feed stock with gaseous ozone was found[26] to result in greatly enhanced susceptibility to cellulase enzyme hydrolysis and to digestion by rumen microorganisms. The treated feed stock can then be used as a source of glucose or animal feed.

The concentration-time products for 99% inactivation of *Giardia lamblia* cysts were found by Wickramanayake *et al.*[27] to be significantly lower than those reported for chlorine. The same investigators[28] in a similar study determined that inactivation kinetics of *Naegleria gruberi* and *Giardia muris* deviated from Chick's law, but Watson's law correlated the ozone concentration with the contact time required for 99% inactivation. Ozone was 9 times more effective against *N. gruberi* cysts at 25°C and pH 7 than free chlorine.

Anselmi *et al.*[29] studied the mass transfer of ozone from bubbles to the bulk liquid in a laboratory batch reactor and developed a model capable of providing a correlation between mass transfer coefficient and stirrer speed and superficial gas velocity. Foller and Goodwin[30] reported progress in research on electrochemical ozone generation techniques. Possible advantages over corona discharge include higher concentrations, use of inexpensive low-voltage DC power supplies, elimination of feed air preparation, reduced size and weight, and aqueous phase generation.

Venosa *et al.*[31] evaluated the disinfection effectiveness of ozone and ultraviolet in various combinations (sequential and simultaneous) and found that, when UV either preceded or followed ozone, the combined treatment reduced the ozone dose needed to achieve the target fecal coliform standard by as much as 80%. The combination was estimated to be cost-effective for medium and large-scale plants but not for small-scale plants. Whitby *et al.*[32] found UV disinfection to be a cost-effective alternative to other forms of wastewater disinfection. Geometric mean fecal coliform numbers before and after 3 hours of photoreactivation were maintained below the limit of 200/100 mL. The UV irradiated effluent was not toxic to rainbow trout. Severin *et al.*[33,34] developed several UV disinfection models describing the inactivation kinetics of *E. coli, Candida parapsilosis,* and f2 bacteriophage in a batch reactor and a completely mixed flow-through reactor. The series-event model was judged to be superior to multi-target kinetics because it better represented the known mechanism of UV inactivation. The mixed second-order model adequately related the response of f2 virus in the two reactors but failed to relate batch and continuous flow responses of the bacterium and yeast. In a further study on mixing effects in UV disinfection, the same researchers[35] found that minor degrees of wall flow or shortcircuiting may result in major changes in effluent quality, especially at high UV solution absorbance.

Kuse[36] reported excellent performance of UV in disinfecting groundwaters mixed with household wastewaters at flow rates of 5.6 to 56 L/s. For water showing 84% UV transmission, a 3-log destruction of coliform bacteria was obtained at a flow of 11.1 L/s. Qualls *et al.*[37] reported no significant difference between the most probable number and standard single-step membrane filtration methods for enumerating total and fecal coliform numbers in UV-irradiated effluent.

Restaino *et al.*,[38] studying the antimicrobial effects of ionizing radiation on contaminated cacao beans, determined that 0.5 Mrad of gamma radiation reduced the microorganism content by 2.49 and 3.03 log units at temperatures of 35 and 50°C, respectively. Cleland *et al.*[39] reviewed electron beam irradiation as a practical and economical method of disinfecting liquid municipal sludges and also considered the possibilities of treating wastewater and drinking water with high energy electrons. Trump *et al.*[40] also concluded that use of machine-accelerated electrons to disinfect both wastewater and sludge is practical and economical.

Stramer and Cliver[41] examined glutaraldehyde, hydrogen peroxide, heat treatment, and a combination of heat and peroxide to disinfect septage. They concluded that combining heat (55°C) and peroxide was the most effective against all bacteria and viruses but that the combination was not practical for on-site use. Blanck *et al.*[42] compared how various sterilization methods affected the toxicity and chemical composition of textile industry wastewater. The methods compared were heat treatment, UV-radiation, filtration, centrifugation, homogenization, sonication, and chemical treatment with diethyl pyrocarbonate. They concluded that filtration and centrifugation should be avoided because removal of particles severely altered the toxic properties of the wastewater. Koch and Euler[43] demonstrated that adding lime to pig slurry to give a pH of 11.5 completely inactivated pseudorabies viruses contained in dialysis tubes. Gabrilevskaya *et al.*[44] found that contacting municipal wastewaters with calcium oxide at doses of 1000 mg/L or more for 90 minutes effected complete removal of coliforms from an initial density of 8×10^6/100 mL. Kato and Kazama[45] determined the maximizing sterilizing effect of potassium ferrate on coliforms was in a sample solution buffered at pH 6–8 regardless of the kind of buffer solution used. Medrish *et al.*[46] conducted a technical and economic assessment of direct electrolysis for water disinfection. They found that effective disinfection of groundwaters and surface waters containing 20 to 50 mg/L chloride can be achieved at plants with capacities of 800 to 1000 m^3/d. Greater flows could be disinfected effectively if the chloride levels were higher.

Gerba *et al.*[47] tested a quaternary ammonium-type anion exchange resin as a contact water viral disinfectant. They observed a three-log reduction of poliovirus and rotavirus as a result of removal and inactivation by the resin. Insoluble quaternary ammonium salts bound to porous glass surfaces inactivated suspensions of *E. coli* and yeast passed through them.[48] The antibacterial activity of the agent, which had a dodecyl alkyl chain, was mainly from adsorption and thus decreased gradually during continuous treatment. McConnell *et al.*[49] studied reovirus removal and inactivation by slow-rate sand filtration (SSF). The SSF process was able to reduce seeded reovirus in influent water by a minimum of 4-log concentration units under certain conditions of water quality, flow rate, and bed construction. Apparently, the reoviruses were inactivated in the filter, since no infectious reovirus could be detected in clean or mature sand bed media. When heterotrophic bacteria, coliforms, and pathogens were grown on granular activated carbon particles and then treated for 1 hour with 1.4 to 1.6 mg/L free chlorine, no decrease in viable counts was observed.[50] Scanning electron microscopic examinations revealed that the GAC particles were colonized by bacteria in the cracks and crevices and were coated with an extracellular slime layer, thereby providing a mechanism whereby disinfection barriers can be breached by pathogens. McRae and Evans[51] studied the adsorption and desorption of bacteria to magnetite and found that three adsorption stages reduced bacterial numbers by 5-log cycles. Removal of calcium and magnesium from the magnetite surface by acid washing improved desorption.

Hauser[52] conducted a 2-year pilot program in Roseville, CA, on water hyacinth aquatic treatment systems. The water hyacinths kept the effluent BOD and suspended solids well below 10 mg/L, thereby greatly enhancing the ease of effluent disinfection by chlorination.

Fliermans and Harvey[53] evaluated the biocidal agent 1-bromo-3-chloro-5,5 dimethylhydantoin (BCD) on an industrial cooling tower containing *Legionella pneumophila*. At concentrations greater than 2 mg/L BCD, the agent was not effective in reducing *L. pneumophila* to source water concentrations.

A treatise reviewing viral pollution of the environment was published by the CRC Press in late 1983.[54] The book, edited by Berg, contained among other things an entire section on removal of viruses from waters, wastewaters, and sludges by various treatment processes, including disinfection.

ANALYTICAL PROCEDURES

Aieta *et al.*[55] described an iodometric procedure for measuring residuals of chlorine, chlorine dioxide, chlorite and chlorate in water. Sample pretreatment and pH adjustment were employed to differentiate among the various chlorine species. The detection limits in drinking water are felt to be about 0.05, 0.02, 0.02, and 0.25 mg/L for chlorine dioxide, chlorine, chlorite, and chlorate, respectively.

Mehran *et al.*[56] described a liquid-liquid extraction method for use in the analysis of trihalomethane in drinking water. The extraction is accomplished by pentane and the extract is then subjected to gas chromatographic analysis. The detection limit in this method is estimated to be about 0.1 μg/L. Huang and Smith[57] reported on a spectrophotometric method for measuring the total concentration of trihalomethanes in drinking water. The procedure is based on the Fujiwara reaction, which is characterized by the red color that develops when a halogen compound is treated with sodium hydroxide and pyridine. The method is proposed as a semi-quantitative screening technique for trihalomethanes at water treatment plants not equipped with a gas chromatograph.

Scully *et al.*[58] described a method to analyze for organic and inorganic chloramines by derivatization with 5-(dimethylamino) naphthalene-1-sulfinic acid ($DANSO_2H$). The chloramine derivatives are separated through the use of high performance liquid chromatography. The kinetics and mechanism of the derivatization reaction are discussed. Scully *et al.*[59] also described cyclic voltametry of organic and inorganic N-chloramines in aqueous solution.

Madec and Trebern[60] reported on the impact of high concentrations of chloride ion on the spectrophotometric determination of tribromamine in aqueous solution. Onodera *et al.*[61] reported on the isotachophoretic determination of chlorinated carboxylic acids formed during the chlorination of phenol.

STABILITY OF DISINFECTANTS

Olivieri *et al.*[62] employed a test water distribution system to evaluate the stability and effectiveness of free chlorine, combined chlorine, and chlorine dioxide. Free chlorine and chlorine dioxide were the least stable disinfectants and maintaining detectable residuals of these compounds under low flow conditions was difficult. Wong and Oatts[63] examined the disappearance of chlorine in estuarine and sea water. Dissolved organic matter was separated into nominal molecular weight groups by ultrafiltration. Estuarine waters were found to have a higher demand at chlorine dosages of 5 mg/L. In 23 hours, about 90% of the added chlorine disappeared in estuarine waters whereas 60 to 75% of that added to sea water dissipated in the same time period. At least two thirds of the chlorine demand occurred in the first 5 hours.

Worley and Burkett[64] evaluated the stability of 3-chloro-4,4-dimethyl-2-oxazolidinone, a newly described chloramine, in aqueous solution and in dry form. They found this chloramine considerably more stable in dry storage and in water than was calcium hypochlorite. The stability of this chloramine may make it useful in the disinfection of swimming pools and potable water in remote areas.

Gould *et al.*[65] reported the formation of stable organic chloramines during the aqueous chlorination of cytosine and 5-methylcytosine. Antelo *et al.*[66] described the kinetics and mechanism of the decomposition of N-chloro-2-(methylamino) ethanol in aqueous solution.

Bancroft *et al.*[67] studied the impact of oxidation competition on disinfection using ozone. Natural waters were employed and the amount of ozone required to reach the same level of disinfection varied directly with both total organic carbon and the oxidation competition value.

Haas and Karra[68] analyzed previously published data on the chlorine demand exerted by three different effluents using various rational kinetic models. A satisfactory fit to the data was obtained by employing a parallel first order decay model that assumed a rapidly and slowly decaying chlorine fraction. Approximately 10 to 40% of the chlorine decayed with a rate constant of 1/min; the remaining residual decayed with a rate constant of 0.003/min.

FORMATION AND CONTROL OF BYPRODUCTS

Love *et al.*[69] described the protocol that the United States Environmental Protection Agency followed in assessing the fate of organic chemicals in drinking water treatment. The compounds include those formed as a by-product of disinfection. The protocol is a three tiered approach consisting of bench scale, pilot plant, and full-scale testing.

Howard *et al.*[70] studied the reaction of hypochlorite with resorcinol in sea water. Seventeen products were identified. In the presence of bromide and in acidic solutions, formation of brominated compounds was favored. In alkaline solutions, formation of chlorinated products was favored. Increasing concentrations of chlorine lead to ring cleavage and the production of trihalomethanes. Onodera *et al.*[71] identified products formed by the chlorination of aqueous solutions of phenol at 20°C. Several chlorinated phenoxyphenols were detected. Onodera *et al.*[72] also reported the formation of many mutagens from these reactions and their removal by activated carbon.

Briley *et al.*[73] determined the amount of trihalomethanes (THMs) produced by the chlorination of three species of algae, *Anabaena cylindrica, Scenedesmus quadricauda,* and *Pediastrum boryanum.* THMs were produced by all three species when either they or their extracellular products were chlorinated. Wachter and Andelman[74] examined factors influencing the production of organohalide compounds upon chlorination of algal extracellular products. In general, organohalide products were reduced by decreases in temperature and decreases in contact time. The organohalide-forming potentials of the blue-green alga studied tended to be higher than those for green algae.

Coleman *et al.*[75] identified nine halogenated products from the chlorination of a model humic acid compound. The identified compounds accounted for about 25% of the total organic halogen (TOX) content of the aqueous chlorinated humic acid solution. The impact of the presence of bromide during chlorination was evaluated to a limited extent also. Arai *et al.*[76] reported on the formation of products from the chlorination of fulvic acid. Lin and Carlson[77] identified products formed when 18 environmentally significant heterocycles were subjected to dilute aqueous solutions of chlorine, chlorine dioxide, and chloramine. Reactions with hypochlorous acid generated products that incorporate chlorine as well as oxygen into the molecule. Chlorine dioxide yielded predominantly oxygenation products. Reactions involving chloramines ($NH_2Cl/NHCl_2$) proceed at a very slow rate relative to those involving HOCl or ClO_2 and significant products from hetero-PAH should not be observed during normal water disinfection. The products formed in the aqueous medium are often different from those formed in organic solvents. Also, some of the degradation products exhibit adverse biological activity.

Aizawa *et al.*[78] reported on the total organic chlorides formed by chlorination of several organic compounds. Additional studies were conducted on the chlorination of methylamine,[79] alanine,[80] 4-nitrophenol,[81] and caffeine.[82]

Lin *et al.*[83] investigated the reaction of chlorine with biphenyl and naphthalene in aqueous solution in the presence of potassium bromide. The reactions resulted in the loss of organic substrate and the formation of a series of chlorinated and brominated products. Chloramine (pH > 6.0) and chlorine dioxide (pH 4.5 to 7.5) in the presence or absence of bromide resulted in no substantial loss of biphenyl or naphthalene.

The occurrence of trihalomethanes in four chlorinated drinking water systems was reported by de Fernicola and de Azevedo.[84] THM concentrations ranged from 0.07 mg/L to 0.13 mg/L with increasing amounts found the farther away from the treatment plant the samples were taken. Although THM's were not found in the raw waters, those supplies that had higher concentrations of total organic chlorine also exhibited higher concentrations of THM's in the treated tap water.

The results of brominating unsaturated aliphatic carboxylic acids,[85] 4-nitrophenol[81] and p-acetoluidide[86] were also reported. Rao and Dalve[87] investigated the kinetics and mechanism of the bromination of aromatic compounds by N-bromosuccinimide. Tee and Bennett[88] reported on the kinetics of brominating anisole.

Removal of THM precursors was reported by several investigators. Curtis *et al.*[89] described the results from a pilot scale 6.3 L/s system of preozonation followed by biological activated carbon. Both anaerobic and aerobic carbon columns were

compared. Argaman *et al.*[90] investigated the control of haloform formation in bench scale and pilot plant studies consisting of flocculation, settling, filtrations, granular activated carbon treatment, and ozonation. Disinfection with a free chlorine residual without formation of high trihalomethane concentrations was achieved only with the GAC treated water. Chlorine dioxide was also effective in minimizing THM production, but demand was high without GAC treatment. Chloramine achieved the desired disinfection while avoiding THM formation with any of the treatment trains employed.

Reckhow and Singer[91] evaluated the removal of organic halide precursors by preozonation and alum coagulation. Alum coagulation removed all precursors tested to a significant extent. Under the test conditions employed, preozonation hindered alum coagulation of organic precursors both with an aquatic fulvic acid solution and a moderately colored raw drinking water. Hoehn *et al.*[92] investigated the impact of algal produced compounds on alum coagulation of raw drinking waters. In this study, alum coagulation reduced THM precursors by about 50%, and its effectiveness appeared not to be altered by variations in algal or bacterial population densities. Yields of THMs generally were greater when biological activity in the reservoir was high.

Glaze and Wallace[93] conducted a pilot plant study of the control of trihalomethane precursors in drinking water through granular activated carbon treatment of both ozonated and unozonated water. At the 2 to 3.5 mg/L ozone dosages employed in this study, no differences in removals were noted. The GAC columns outperformed the ozone-GAC systems in terms of cumulative TOC or THMFP removed.

Pringle[94] reported on the rate constants for the destruction of organic compounds through ozonation and UV radiation. Recently published data were examined to determine empirical rate constants, one for O_3 oxidation and the other for O_3/UV photooxidation, of various organic compounds including THM precursors. The data indicate the dominant effect of the latter reaction process.

Edzwald[95] examined direct filtration with cationic polymers as coagulants for the removal of THM precursors in a pilot plant. These results were compared to those from two full scale plants which employ alum for coagulation. The filtration was judged effective and UV absorbance was determined to be a good surrogate for monitoring the removals of non-purgeable total organic carbon and THM precursors at the two conventional plants. Kaczma *et al.*[96] reported the volatilization rates of several haloforms from aqueous solution.

Worley *et al.*[97] noted that a newly described chloramine was much less reactive with organic matter than hypochlorite was. They concluded that the potential for forming THM's was much less than it is for hypochlorous acid.

Wolfe *et al.*[98] reviewed the use of chloramines as an alternative to chlorine in drinking water systems. While chloramines offer a major advantage in their low, if any, reactivity with organic matter to form THMs, the issues of their effectiveness in controlling microorganisms and their potential health hazard have not been settled.

OTHER CHEMISTRY

Kuo and Soong[99] studied the oxidation of benzene by ozone while Gurol and Nekouinaini[100] reported on the kinetics of reactions between ozone and aqueous solutions of substituted phenols. Decoret *et al.*[101] evaluated data relative to the mechanisms of the initial attack of ozone on some aromatic compounds in aqueous solution.

Inman and Johnson[102] reported on the disproportionation of monobromamine and the formation of dibromamine. The kinetics of dibromamine formation were studied in solution with ammonia present in molar excess over oxidizing bromine. The reaction was observed to be strongly catalyzed by phosphate and to have ammonia dependence beyond that required for monobromamine formation. Investigations of the interaction of aqueous chlorine with activated carbon were reported by McGuire and Suffet,[103] by Kruglitskii *et al.*,[104] and Chen *et al.*[105]

Tang and Gordon[106] evaluated the stoichiometry for the reaction of chlorite ion and hypochlorous acid at pH 5. The stoichiometry varied with the initial concentration ratio of the reactants, suggesting parallel reactions. The yield of chlorine dioxide was shown to vary with the initial concentration ratio of hypochlorous acid to chlorite ion as well as the contact time between reactants. The formation of molecular oxygen was also postulated. Ozawa and Kwan[107] studied the reactive character of chlorine dioxide in aqueous solution through electron spin resonance.

Wong[108] investigated chlorination and filtration for the removal of iron and manganese. At pH 8.4 and above, the chlorination process was judged to effectively remove iron and manganese at a cost less than that for potassium permanganate-manganese greensand filtration. Nakhijiri *et al.*[109] evaluated the impact of the presence of free chlorine on the copper corrosion in Seattle's water supply distribution system.

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REFERENCES

1. Water Pollution Control Federation Disinfection Committee, "Proceedings preconference workshop on wastewater disinfection alternatives—design, operation, and effectiveness." Water Pollut. Control Fed., Washington, D. C. (1983).
2. Water Pollution Control Federation Disinfection Committee, "Wastewater disinfection: a state-of-the-art report." Water Pollut. Control Fed., Washington, D. C. (1984).
3. Seyfried, P. L., *et al.*, "Impact of Sewage Treatment Plants on Surface Waters." *Can. J. Public Health*, 75(1), 25 (1984).
4. Simmonds, R. S., *et al.*, "Enteric Viruses in New Zealand Wastewaters." *N. Z. J. Sci.*, 26(4), 437 (1983).
5. Goyal, S. M., *et al.*, "Viruses in Groundwater Beneath Sewage Irrigated Cropland." *Water Res.*, 18(3), 299 (1984).
6. Hopkins, R. S., *et al.*, "Community Waterborne Gastroenteritis Outbreak: Evidence for Rotavirus as the Agent." *Am. J. Public Health*, 74(3), 263 (1984).
7. Berk, S. G., and Botts, J. A., "Indirect Effects of Chlorinated Waste-Water on Bacteriovorous Protozoa." *Environ. Pollut.* (Series A), 34(3), 237 (1984).
8. Sanders, J. G., "Longevity of Algal Inhibition After Chlorination of Estuarine Water." *Environ. Sci. Technol.*, 18, 383 (1984).
9. Levy, R. V., *et al.*, "Novel Method for Studying the Public

Health Significance of Macroinvertebrates Occurring in Potable Water." *Appl. Environ. Microbiol.*, 47(5), 889 (1984).
10. Murray, G. E. *et al.*, "Effect of Chlorination on Antibiotic Resistance Profiles of Sewage-Related Bacteria." *Appl. Environ. Microbiol.*, 48(1), 73 (1984).
11. Gasser, J. A., "Disinfection of nitrified effluents." *J. Water Pollut. Control Fed.*, 56(4), 385 (1984).
12. Polprasert, C., and Rajput, V. S., "Study on Chlorine Disinfection of Pond Effluent." *Water Res.*, 18(5), 513 (1984).
13. Dubov, Y. M., *et al.*, "Electrolysis Plant for Sodium Hypochlorite Production for the Disinfection of Household Sewage." *Khim. Tekhnol. Vody* (Sov.), 6(3), 277 (1984); *Chem. Abstr.*, 101, 136347e (1984).
14. Harakeh, M. S., "The Combined Effects of Various Disinfectants Against Poliovirus 1 in a Municipal Wastewater Effluent." *FEMS Microbiol. Lett.* 23(1), 21 (1984).
15. Churn, C. C., *et al.*, "The Inactivation Kinetics of H-1 Parvovirus by Chlorine." *Water Res.*, 18(2), 195 (1984).
16. Churn, C. C., et al., "Mechanism of Chlorine Inactivation of DNA-Containing Parvovirus H-1." *Appl. Environ. Microbiol.*, 46(6), 1394 (1983).
17. Berman, D., and Hoff, J. C., "Inactivation of Simian Rotavirus SA11 by Chlorine, Chlorine Dioxide, and Monochloramine." *Appl. Environ. Microbiol.*, 48(2), 317 (1984).
18. Ward, N. R., *et al.*, "Effect of pH, Application Technique, and Chlorine-to-Nitrogen Ratio on Disinfectant Activity of Inorganic Chloramines with Pure Culture Bacteria." *Appl. Environ. Microbiol.*, 48(3), 508 (1984).
19. Engel, J. P. *et al.*, "Inactivation of *Naegleria gruberi* Cysts by Chlorinated Cyanurates." *Appl. Environ. Microbiol.*, 46(5), 1157 (1983).
20. Marchin, G. L., *et al.*, "Effect of Resin Disinfectants -I_3 and -I_5 on *Giardia muris* and *Giardia lamblia*." *Appl. Environ. Microbiol.*, 46(5), 965 (1983).
21. Mayack, L. A., *et al.*, "Comparative Effectiveness of Chlorine and Chlorine Dioxide Biocide Regimes for Biofouling Control." *Water Res.*, 18(5), 593 (1984).
22. Schmidt, H., "Prevention of Organic Deposits and Microbial Control in Industrial Cooling Water Systems." *Wasser, Luft*, and *Betrieb*, 27(9), 12 (1983).
23. Wilde, E. W., *et al.*, "Comparison of Chlorine and Chlorine Dioxide Toxicity to Fathead Minnows and Bluegill." *Water Res.*, 17(10), 1327 (1983).
24. Junkins, R., "Operation and Maintenance of Selected Ozone and Ultraviolet Disinfection Systems." EPA–600/2–84–087, Environ. Prot. Agency (U. S.) (1984).
25. Bancroft, K., *et al.*, "Ozonation and Oxidation Competition Values. Relationship to Disinfection and Microorganisms Regrowth." *Water Res.*, 18(4), 473 (1984).
26. Neely, W. C., "Factors Affecting the Pretreatment of Biomass with Gaseous Ozone." *Biotechnol. Bioeng.*, 26(1), 59 (1984).
27. Wickramanayake, G. B., *et al.*, "Inactivation of *Giardia lamblia* Cysts with Ozone." *Appl. Environ. Microbiol.*, 48(3), 671 (1984).
28. Wickramanayake, G. B., *et al.*, "Inactivation of *Naegleria* and *Giardia* cysts in water by ozonation." *J. Water Pollut. Control Fed.*, 56, 983 (1984).
29. Anselmi, P. G., *et al.*, "Ozone Mass Transfer in Stirred Vessel." *Ozone: Sci. Eng.*, 6, 17 (1984).
30. Foller, P. C., and Goodwin, M. L., "The Electrochemical Generation of High Concentration Ozone for Small-Scale Applications." *Ozone: Sci. Eng.*, 6, 29 (1984).
31. Venosa, A. D., *et al.*, "Disinfection of secondary effluent with ozone/UV." *J. Water Pollut. Control Fed.*, 56, 137 (1984).
32. Whitby, G. E. *et al.*, "Ultraviolet disinfection of secondary effluent." *J. Water Pollut. Control Fed.*, 56, 844 (1984).
33. Severin, B. F., *et al.*, "Inactivation kinetics in a flow-through UV reactor." *J. Water Pollut. Control Fed.*, 56, 164 (1984).
34. Severin, B. F., *et al.*, "Mixing effects in UV disinfection." *J. Water Pollut. Control Fed.*, 56, 881 (1984).
35. Severin, B. F., *et al.*, "Kinetic Modeling of UV Disinfection of Water." *Water Res.*, 17(11), 1669 (1983).
36. Kuse, D., "Large-Scale Water Purification by Ultraviolet Rays." *Eau, Ind. Nuisances* (Fr.), 76, 31 (1983); *Chem. Abstr.*, 100, 12342j (1984).
37. Qualls, R. G., *et al.*, "Comparison of Methods of Enumerating Coliforms After UV Disinfection." *Appl. Environ. Microbiol.*, 48(4), 699 (1984).
38. Restaino, L., *et al.*, "Antimicrobial Effects of Ionizing Radiation on Artificially and Naturally Contaminated Cacao Beans." *Appl. Environ. Microbiol.*, 47(4), 886 (1984).
39. Cleland, M. R., *et al.*, "Electron Beam Process Design for the Treatment of Wastes and Economic Feasibility of the Process." *Radiat. Phys. Chem.*, 24(1), 179 (1984).
40. Trump, J. G., *et al.*, "Disinfection of Sewage Wastewater and Sludge by Electron Treatment." *Radiat. Phys. Chem.*, 24(1), 55 (1984).
41. Stramer, S. L., and Cliver, D. O., "Septage Treatments to Reduce the Numbers of Bacteria and Polioviruses." *Appl. Environ. Microbiol.*, 48(3), 566 (1984).
42. Blanck, H., *et al.*, "Effects of Various Sterilization Methods on Toxicity and Chemical Composition of Industrial Wastewater Samples." *Water Res.*, 17(9), 965 (1983).
43. Koch, K. M. A., and Euler, B., "Lime as a Disinfectant for Pig Slurry Contaminated with Aujeszky's Disease (Pseudorabies) Virus (ADV)." *Agric. Wastes*, 9(4), 289 (1984).
44. Gabrilevskaya, L. N., *et al.*, "Hygienic Evaluation of the Effectiveness of Disinfecting Wastewater with Calcium Oxide." *Gig. Sanit.* (Sov.), 2, 66 (1984); *Chem. Abstr.*, 100, 144474p (1984).
45. Kato, K., and Kazama, F., "Sterilizing Properties of Potassium Ferrate (VI). II. Relation Between Buffer Action of Water Sample and Sterilization." *Mizu Shori Gijutsu* (Jpn.), 25(1), 9 (1984); *Chem. Abstr.*, 101, 28037v (1984).
46. Medrish, G. L., *et al.*, "Use of Direct Electrolysis for Water Disinfection." *Vodosnabzh. Sanit. Tekh.* (Sov.), 1, 8 (1984); *Chem. Abstr.*, 100, 108897v (1984).
47. Gerba, C. P., *et al.*, "Removal of Poliovirus and Rotavirus from Tapwater by a Quaternary Ammonium Resin." *Water Res.*, 18(1), 17 (1984).
48. Nakagawa, Y., *et al.*, "Disinfection of Water with Quaternary Ammonium Salts Insolubilized on a Porous Glass Surface." *Appl. Environ. Microbiol.*, 47(3), 513 (1984).
49. McConnell, L. K., *et al.*, "Reovirus Removal and Inactivation by Slow-Rate Sand Filtration." *Appl. Environ. Microbiol.*, 48(4), 818 (1984).
50. LeChevallier, M. W., *et al.*, "Disinfection of Bacteria Attached to Granular Activated Carbon." *Appl. Environ. Microbiol.*, 48(5), 918 (1984).
51. MacRae, I. C., and Evans, S. K., "Removal of Bacteria from Water by Adsorption to Magnetite." *Water Res.*, 18(11), 1377 (1984).
52. Hauser, J. R., "Use of water hyacinth aquatic treatment system for ammonia control and effluent polishing." *J. Water Pollut. Control Fed.*, 56(3), 219 (1984).
53. Fliermans, C. B., and Harvey, R. S., "Effectiveness of 1-Bromo-3-Chloro-5,5-Dimethylhydantoin Against *Legionella pneumophila* in a Cooling Tower." *Appl. Environ. Microbiol.*, 47(6), 1307 (1984).
54. Berg, G. (Ed.), "Viral Pollution of the Environment." CRC Press, Boca Raton, Fla. (1983).
55. Aieta, E. M., *et al.*, "Determination of Chlorine Dioxide, Chlorine, Chlorite and Chlorate in Water." *J. Am. Water Works Assoc.*, 76(1), 64 (1984).
56. Mehran, M. F., *et al.*, "Simplified Liquid-Liquid Extraction

Method for Analysis of Trihalomethanes in Drinking Water." *J. Chromatogr. Sci.*, **22**(6), 242 (1984).
57. Huang, J. Y. C., and Smith, G. C., "Spectrophotometric Determination of Total Trihalomethanes in Finished Waters." *J. Am. Water Works Assoc.*, **76**(4), 168 (1984).
58. Scully, F. E., Jr., *et al.*, "Derivatization of Organic and Inorganic N-Chloramines for High-Performance Liquid Chromatographic Analysis of Chlorinated Water." *Environ. Sci. Technol.* **18**, 787 (1984).
59. Scully, F. E., Jr., *et al.*, "Cyclic Voltammetry of Organic and Inorganic N-Chloramines in Aqueous Solution." *Anal. Chem.*, **56**, 1449 (1984).
60. Madec, C., and Trebern, B., "Effect of High Chloride Ion Concentrations on the Quantitative Spectrophotometric Determination of Tribromamine in Aqueous Media." *Water Res.*, **18**, 1291 (1984).
61. Onodera, S., *et al.*, "Isotachophoretic Determination of Chlorinated Carboxylic Acids Formed During Chlorination of Phenol with Hypochlorite in Dilute Aqueous Solution." *J. Chromatogr.*, **287**, 176 (1984).
62. Olivieri, V. P., *et al.*, "Stability and Effectiveness of Chlorine Disinfectants in Water Distribution Systems." National Technical Information Service, Springfield, Va. (1984).
63. Wong, G. T. F., and Oatts, T. J., "Dissolved Organic Matter and the Dissipation of Chlorine in Estuarine Water and Seawater." *Water Res.*, **18**(4), 501 (1984).
64. Worley, S. D., and Burkett, H. D., "Stability in Water of a New Chloramine Disinfectant as a Function of pH, Temperature, and Water Quality." *Water Res. Bull.*, **20**(3), 365 (1984).
65. Gould, J., *et al.*, "The Formation of Stable Organic Chloramines During the Aqueous Chlorination of cytosine and 5-Methylcytosine." *Water Res.*, **18**, 991 (1984).
66. Antelo, J., *et al.*, "Kinetics and Mechanism of the Decomposition of N-Chloro-2-(methylamino) ethanol in Aqueous Solution." *Environ. Sci. Technol.*, **18**, 97 (1984).
67. Bancroft, K., *et al.*, "Ozonation and Oxidation Competition Values; Relationship to Disinfection and Microorganisms Regrowth." *Water Res.*, **18**(4), 473 (1984).
68. Haas, C. N., and Karra, S. B., "Kinetics of wastewater chlorine demand exertion." *J. Water Pollut. Control Fed.*, **56**, 170 (1984).
69. Love, O. T., Jr., *et al.*, "Research for the Treatment of Organics in Drinking Water." National Technical Information Service, Springfield, Va., PB84–177757, (1984).
70. Howard, A. G., *et al.*, "Studies of the Halogenation of Dissolved Organic Material During the Chlorination of Saline Cooling Waters, Using the Model Compound Resorcinol." *Water Res.*, **18**(6), 735 (1984).
71. Onodera, S., *et al.*, "Chemical Changes of Organic Compounds in Chlorinated Water. IX. Formation of Polychlorinated Phenoxyphenols During the Reaction of Phenol with Hypochlorite in Dilute Aqueous Solution." *J. Chromatogr.*, **288**(1), 91 (1984).
72. Onodera, S., *et al.*, "Chemical Changes of Organic Compounds in Chlorinated Water. VII. Formation of Mutagenic Substances by the Reactions of Phenylphenols with Hypochlorite in Dilute Aqueous Solution and Their Absorbability by Activated Carbon." *Eisei Kagaku*, **30**, 3 (1984).
73. Briley, K. F., *et al.*, "Alternative Water Disinfection Schemes for Reduced Trihalomethane Formation", Volume 2. Algae as Precursors for Trihalomethanes in Chlorinated Drinking Water. National Technical Information Service, Springfield, Va., PB84-129006 (1984).
74. Wachter, J. K., and Andelman, J. B., "Organohalide Formation on Chlorination of Algal Extracellular Products." *Environ. Sci. Technol.*, **18**, 811 (1984).
75. Coleman, W. E., *et al.*, "Gas Chromatography/Mass Spectroscopy Analysis of Mutagenic Extracts of Aqueous Chlorinated Humic Acid. A Comparison of the Byproducts to Drinking Water Contaminants." *Environ. Sci. Technol.*, **18**, 674 (1984).
76. Arai, H., *et al.*, "Major Aqueous Chlorination Products of Oxidized Fulvic Acid." *Chem. Lett.* **8**, 1435 (1984).
77. Lin, S., and Carlson, R. M. "Susceptibility of Environmentally Important Heterocycles to Chemical Disinfection: Reactions with Aqueous Chlorine, Chlorine Dioxide, and Chloramine." *Environ. Sci. Technol.*, **18**, 743 (1984).
78. Aizaiwa, T., *et al.*, "Characteristics of the Formation of Total Organic Chlorides from Organic Compounds by Aqueous Chlorination." *Suiskitsu Odaku Kenkyu* (Japanese), **7**, 108 (1984).
79. Ponci, J., *et al.*, "Kinetic Studies on the Chlorination of Methylamine by Sodium Hypochlorite in Dilute Aqueous Medium." *Environ. Technol. Lett.* (French), **5**, 263 (1984).
80. LeCloires, C., *et al.*, "Chlorination of Alpha-Amino Acids in Dilute Aqueous Medium; the Examples of Alanine." *C. R. Acad. Sci., Ser. 2* (French), **298**, 559 (1984).
81. Otero, C., *et al.*, "Halogenation of 4-Nitrophenol with Basic Aqueous Solution of Chlorine and Bromine." *An. Quim. Ser. A.*, (Spanish), **80**, 78 (1984).
82. Gould, J., and Richards, J., "The Kinetics and Products of the Chlorination of Caffeine in Aqueous Solution." *Water. Res.*, **18**, 1001 (1984).
83. Lin, S., *et al.*, "Facile Incorporation of Bromine into Aromatic Systems under Conditions of Water Chlorination." *Environ. Sci. Technol.*, **18**, 985 (1984).
84. de Fernicola, N. A. G. G., and de Azevedo, F. A., "Water Levels of Trihalomethanes (THM) in Four Different Supply Systems from Sao Paulo State, (Brazil)." *J. Environ. Health*, **46**, 4, 187 (1984).
85. Farook, S., *et al.*, "Kinetics and Mechanism of Bromine Addition to Derivatives of Unsaturated Aliphatic Carbolic Acids in Aqueous Solution." *Bull. Chem. Soc. Jpn.*, **57**, 1394 (1984).
86. Dangat, V., *et al.*, "Bromination of p-Acetotoliudide. In Aqueous Medium: Substituent Effect." *Indian J. Chem. Sect. A.*, **23A**, 237 (1984).
87. Rao, T., and Dalve, S., "Kinetics and Mechanism of the Bromination of Aromatic Substrates by N-Bromosuccinimide in Aqueous Solution." *Curr. Sci.*, **53**, 258 (1984).
88. Tee, O., and Bennett, J., "The Effect of Alpha-Cyclodextrin Upon the Kinetics of Aqueous Bromination of Anisole." *Can. J. Chem.*, **62**, 1585 (1984).
89. Curtis, F. W., *et al.*, "Pilot Plant Project for Removing Organic Substances from Drinking Water." National Technical Information Service, Springfield, Va., PB84–128685, (1984).
90. Argaman, Y., *et al.*, "Preventing Haloform Formation in Treated Surface Water: A Case Study." *J. Am. Water Works Assoc.*, **76**(4), 172 (1984).
91. Reckhow, D. A., and Singer, P. C., "The Removal of Organic Halide Precursors by Preozonation and Alum Coagulation." *J. Amer. Water Works Assoc.*, **76**(4), 151 (1984).
92. Hoehn, R. C., *et al.*, "Biologically Induced Variations in the Nature and Removability of TMH Precursors by Alum Treatment." *J. Amer. Water Works Assoc.*, **76**(4), 134 (1984).
93. Glaze, W. H., and Wallace, J. L., "Control of Trihalomethane Precursors in Drinking Water: Granular Activated Carbon With and Without Preozonation." *J. Amer. Water Works Assoc.*, **76**(2), 68 (1984).
94. Prengle, H., Jr., "Experimental Rate Constants and Reactor Considerations for the Destruction of Micropollutants and Trihalomethane Precursors by Ozone with Ultraviolet Radiation." *Environ. Sci. Technol.*, **17**, 743 (1984).
95. Edzwald, J. K., "Removal of Trihalomethane Precursors by Direct Filtration and Conventional Treatment." National Technical Information Service, Springfield, Va., PB84-163278 (1984).
96. Kaczma, S., *et al.*, "Volatilization Rates of Selected Haloforms

from Aqueous Environments, *Environ. Toxicol. Chem.*, **3**, 31 (1984).
97. Worley, S. D., *et al.*, "Tendency of a New Water Disinfectant to Produce Toxic Trihalomethanes." *Water Resour. Bull.*, **20**(3), 369 (1984).
98. Wolfe, R. L., *et al.*, "Inorganic Chloramines as Drinking Water Disinfectants: A Review." *J. Amer. Water Works Assoc.*, **76**(5), 74 (1984).
99. Kuo, C., and Soong, H., "Oxidation of Benzene by Ozone in Aqueous Solutions, *Chem. Eng.*, **28**, 163 (1984).
100. Gurol, M., and Nekouinaini, S., "Kinetic Behavior of Ozone in Aqueous Solutions of Substituted Phenols." *Ind. Eng. Chem. Fundam.*, **23**, 54 (1984).
101. Decoret, C., *et al.*, "Experimental and Theoretical Studies of the Mechanism of the Initial Attah of Ozone on Some Aromatics in Aqueous Medium." *Environ. Technol. Lett.*, **5**, 207 (1984).
102. Inman, G. W., Jr., and Johnson, J. D., "Kinetics of Monobromamine Disproportionation-Dibromamine Formation in Aqueous Ammonia Solutions." *Environ. Sci. Technol.*, **18**, 219 (1984).
103. McGuire, M., and Suffet, I., "Aqueous Chlorine/Activated Carbon Interactions." *J. Environ. Eng.* (N. Y.), **110**, 629 (1984).
104. Kruglitskii, N., *et al.*, "Chemical Nature and Kinetics of the Interaction of Active Chlorine with Activated Carbon in Aqueous Solution." *Dopor. Akad. Nauk. Ukr., R. SR. Ser. B.: Geol., Khim. Biol. Nauki* (Ukranian) **10**, 37 (1984).
105. Chen, A., *et al.*, "Importance of Surface Free Radicals in an Aqueous Chlorination Reaction (Indan-Chlorine Dioxide) Promoted by Granular Activated Carbon." *Carbon*, **22**, 63 (1984).
106. Tang, T-F, and Gordon, G., "Stoichiometry of the Reaction between Chlorite Ion and Hypochlorous Acid at pH 5." *Environ. Sci. Technol.*, **18**, 212 (1984).
107. Ozawa, T., and Kwan, T., "Electron Spin Resonance Studies on the Reactive Character of Chlorine Dioxide (ClO_2) Radical in Aqueous Solution." *Chem. Pharm. Bull.*, **32**, 1587 (1984).
108. Wong, J. M., "Chlorination-Filtration for Iron and Manganese Removal." *J. Amer. Water Works Assoc.*, **76**(1), 76 (1984).
109. Nakhijiri, K. S., *et al.*, "Seattle Distribution System Corrosion Control Study. Volume 5. Counteractive Effects of Disinfection and Corrosion Control." National Technical Information Service, Springfield, Va., PB84–16947 (1984).

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